Temperature Assessment Protocol

July, 1999

Introduction

Water temperature influences the metabolism, behavior, and mortality of fish and other aquatic organisms that affect fish. Natural temperatures of a waterbody fluctuate daily and seasonally. These natural fluctuations do not eliminate indigenous populations, but may affect existing community structure and geographical distribution of species. In fact, such temperature cycles are often necessary to induce reproductive cycles and may regulate other aspects of life history (Mount, 1969). Behnke and Zarn (1976), in a discussion of temperature requirements for endangered western native trout, recognized that populations cannot persist in waters where maximum temperatures consistently exceed 21-22°C, but they may survive brief daily periods of higher temperatures (25.5-26.7°C). Anthropogenic impacts can lead to modifications of these natural temperature cycles, often leading to deleterious impacts on the fishery. Such modifications may contribute to changes in geographical distribution of species and their ability to persist in the presence of introduced species.

Historical Background

The Surface Water Quality Bureau (Bureau) of the New Mexico Environment Department convened a multi-agency workgroup to evaluate current temperature criteria and how the Bureau could best incorporate these criteria into its management activities. This exercise was undertaken as a result of changes in temperature monitoring procedures initiated by the Bureau in 1998, and the resulting data.

Prior to 1998, temperature monitoring by the Bureau was limited to instantaneous streamside measurements taken by a staff member conducting a water quality survey. This resulted in limited information concerning actual dynamics of temperature in New Mexico streams. During 1998, stream sampling surveys used a new device, the continuously recording thermograph, to collect more complete temperature data. These devices may be deployed in streams for extended periods of time, and collect data at preset intervals. Bureau protocols for use of these devices (Appendix A) call for deployment during the critical summer period of May through September, with a data collection interval of one hour. These devices were first deployed in mid-July 1998.

Following deployment, devices were collected and data were downloaded and interpreted. Data review indicated only one stream (Sulphur Creek) of more than 20 evaluated in 1998 had no exceedences of the 20°C standard. Many of these monitoring sites were established on what were considered to be minimally impacted stream reaches. These preliminary results seemed to indicate that the streams evaluated had temperatures that may not support their coldwater fishery designated use.

Procedures for assessing designated use support were conducted using 1997 Bureau protocols. Under these protocols, all physical parameters, including temperature, were evaluated based on a percent-of-exceedences formula. Review of data generated by thermographs brought into question the usefulness of this method of evaluation, as it did not recognize a maximum allowable temperature. In response, the Bureau convened the Temperature Workgroup.

The Workgroup was comprised of representatives from the US Environmental Protection Agency (EPA) Region 6, the US Department of Interior, Fish and Wildlife Service – New Mexico Ecological

Services Field Office, New Mexico Department of Game and Fish – Conservation Services and Fisheries Management Divisions, and the Bureau. The Workgroup held four meetings beginning in December 1998. The Workgroup's task was to develop an assessment protocol that would evaluate designated use support status of New Mexico streams using detailed temperature data collected by the Bureau. The Workgroup was informed of implementation of new sampling procedures and given a general summary of preliminary results. It was the Bureau's wish that the Workgroup develop an assessment protocol independent of any data or *a priori* beliefs that could have been developed from a review of data collected. For this reason, the Workgroup was not given any specific thermograph data, nor were members made aware of specific data collection sites.

The Workgroup decided to conduct a literature review, and to base any recommendations on results of this review and internal discussions held with other agency or department staff. Information collected, that formed the basis for recommendations, is summarized below.

Review of the EPA Criteria Document for Temperature

Following is a summary of temperature information from EPA's September 1988 document "*Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria*."

Preamble: Temperature standards are set to control thermal pollution, or the amount of heated wastes discharged into a waterbody. The following guidelines were developed by the EPA and published in *"Quality Criteria for Water, 1986"* (Gold Book).

Freshwater Aquatic Life

For any time of year, there are two upper limiting temperatures for a location (based on the important sensitive species found there at that time):

1. One limit consists of a maximum temperature for short exposures that is time and species dependent, and

2. The second value is a limit on weekly average temperature that:

    a. In the cooler months, will protect against mortality of important species if the elevated plume temperature is suddenly dropped to the ambient temperature, with the limit being the acclimation temperature minus two °C when the lower lethal threshold temperature equals ambient water temperature;

or

    b. In the warmest months, is determined by adding to the physiological optimum temperature (for growth) a factor calculated as 1/3 of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most sensitive species that are normally present at that location and time;

or

    c. During reproductive seasons, the limit is the temperature that meets site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species. These local requirements should supersede all other requirements when applicable;

or

d. There is a site-specific limit that is found necessary to preserve normal species diversity or prevent appearance of nuisance organisms.

Upper and lower limits have been established for many aquatic organisms. Tabulations of lethal temperatures for fish and other organisms are available. Factors such as diet, activity, age, general health, osmotic stress, and even weather contribute to the lethality of temperature. Aquatic species, thermal acclimation state, and exposure time are considered critical factors.

Effects of sublethal temperatures on metabolism, respiration, behavior, distribution and migration, feeding rate, growth, and reproduction have been summarized by De Sylva (1969). Brett (1960) illustrated that inside the tolerance zone, there is a more restrictive temperature range in which normal activity and growth occur, and an even more restrictive zone inside that in which normal reproduction occurs.

The upper incipient lethal temperature and the LT50 (the highest temperature at which 50% of a sample of organisms can survive) for any given species are determined at that species' highest sustainable acclimation temperature. Generally, the lower end of temperature accommodation for aquatic freshwater species is 0°C.

The following requirements are currently considered necessary and sufficient for development of a protective temperature criteria definition:

1. Maximum sustained temperatures are consistent with maintaining desirable levels of primary and secondary productivity.

2. Maximum levels of metabolic acclimation to warm temperatures that permit return to ambient winter temperatures should artificial sources of heat cease.

3. Time-dependent temperature limitations for survival of brief exposures to temperature extremes, both upper and lower.

4. Restricted temperature ranges for various states of reproduction, including (for fish) gametogenesis, spawning migration, release of gametes, development of embryo, commencement of independent feeding (and other activities) by juveniles, and temperature required for metamorphosis, emergence, or other activities of lower forms.

5. Thermal limits for diverse species composition of aquatic communities, particularly where reduction in diversity creates nuisance growth of certain organisms, or where important food sources are altered.

6. Thermal requirements of downstream aquatic life (in rivers) where upstream diminution of a coldwater resource will adversely affect downstream temperature requirements.

The temperature-time duration for short-term maximum (STM) exposure, such that there is 50% survival, is expressed mathematically by fitting experimental data with a straight line on a semi-logarithmic plot. Time is shown on the log scale; temperature is on the linear scale. To provide for safety, an experimentally derived safety factor of 2°C is applied. In equation form this is:

Equation 1. STM = (log(time)-a)/b

Where:

STM	=	short-term maximum temperature
$\log_{10}$	=	logarithm to base 10 (common log)
a	=	intercept on "y" axis (or logarithmic axis) of the line fitted to experimental data that is available for some species from <u>Water Quality Criteria 1972</u>, Appendix II-C (US EPA, 1972).
b	=	Slope of the line fitted to experimental data and available for some species from <u>Water Quality Criteria 1972</u>, Appendix II-C (US EPA, 1972).
time	=	minutes.

For extensive exposure, the maximum weekly average temperature (MWAT) is expressed as:

Equation 2. MWAT = OT + ((UUILT - OT)/3)

Where:

MWAT	=	maximum weekly average temperature.
OT	=	a reported optimum temperature for the particular life state or function.
UUILT	=	ultimate upper incipient lethal temperature (the upper temperature at which tolerance does not increase with increasing acclimation temperature).

One caveat in determining maximum weekly average temperature is that the limit for short-term exposure must not be exceeded. Some calculated values are available in the literature for species considered important in New Mexico.

EPA Calculated Values for Maximum Weekly Average Temperatures for Growth and Short-term Maxima for Survival of Juveniles and Adults During Summer Months are given in the following table.

Species	Growth[a]	Maxima[b]
Rainbow trout	19	24
Brook trout	19	24
Brown trout	--	25

[a]Calculated according to the maximum weekly average formula (Equation 2).
[b]Based on the short term maximum formula (Equation 1), with acclimation at the weekly average temperature for summer growth (does not indicate exposure period).

Other Literature References

Numerous literature references (Armour, 1991; US EPA, 1986) also recognize the concept of using short-term maxima and weekly average temperatures to protect for temperature effects on fisheries. Of primary importance are protections necessary to support reproducing populations of salmonids in stream segments designated as high quality coldwater fisheries.

Armour (1991) cited the following findings for the calculated short-term maxima (STM) = (log of time - *a*)/*b*. Values for *a* and *b,* intercept, and slope of a line from experimental data, are taken from National Academy of Sciences, Water Quality Criteria (1972) for juvenile brook trout (*Salvelinus fontinalis*), where time = 120 min. This yields a calculated STM of 25.6°C (25.5°C for juvenile brown trout, *Salmo trutta*). To provide a margin of safety for all organisms, this value was reduced by 2°C, resulting in a calculated STM of 23.6°C.

This calculated STM value is consistent with data found in other literature. US EPA (1986) short-term lethal threshold for brook trout and rainbow trout (*Oncorhynchus mykiss*) is given as 24°C, after reduction by the 2°C safety factor. Grande and Andersen (1991) experimentally determined in controlled studies a LT50 for brook trout, brown trout, and rainbow trout to be 25.2°C, 26.2°C, and 26.6°C, respectively. Applying a safety factor of 2°C results in 23.2°C, 24.2 °C, and 24.6°C, respectively, which are similar to US EPA findings. Eaton (1995) developed a Fish Temperature Database Matching System (FTDMS) to document temperatures at which various species were found in natural settings. He reported a 95th percentile temperature (i.e. 95% of all individuals collected were found at temperatures below this value) of 22.3°C for brook trout, 24.1°C for brown trout, and 24.0°C for rainbow trout.

Workgroup Recommendations

Given the broad literature support for temperature evaluations employing a concept of short-term thermal maximum and long-term average value, the Workgroup recommended such an approach be applied in New Mexico. Because the current criterion is 20°C, this value was used as the basis of the assessment protocol.

The specific recommendations from the Workgroup are as follows:

Temperature in High Quality Coldwater Fisheries (HQCWF)

Full Support Instantaneous (hourly) temperatures do not exceed 23.0°C and temperatures do not exceed 20°C for more than four hours in a 24-hour cycle, and for no more than three consecutive days.

Partial Support Instantaneous (hourly) temperatures do not exceed 23.0°C. Temperatures may exceed 20°C for greater than four, but no more than six, hours in a 24-hour cycle, and for no more than three consecutive days.

Not Supported Instantaneous (hourly) temperatures exceed 23.0°C, or temperatures exceed 20 C for more than six hours in a 24-hour cycle, or the allowable interval is exceeded for more than three consecutive days.

During reproductive seasons, temperatures must not impede successful migration, egg incubation, fry rearing, and other reproductive functions of target species.

Temperature in Coldwater Fisheries (CWF)

Full Support Instantaneous (hourly) temperatures do not exceed 24.0°C and temperatures do not exceed 20.0°C for more than six hours in a 24-hour cycle, and for no more than three consecutive days.

Partial Support Instantaneous (hourly) temperatures do not exceed 24.0°C. Temperatures may exceed 20.0°C for greater than six, but no more than eight, hours in a 24-hour cycle, and for no more than three consecutive days.

Not Supported Instantaneous temperatures exceed 24.0° C or temperatures exceed 20.0° C for more than eight hours in a 24-hour cycle, or the allowable interval is exceeded for more than three consecutive days.

Sampling for assessment of these criteria will be accomplished using continuously recording thermographs with a maximum interval of one hour. Data will be collected from May through September.

Other Recommendations

Additional recommendations by the Workgroup:

- Language should be included in any future standard indicating temperature limits are established to protect the entire aquatic community, not just fish species.
- Additional data should be collected on varying stream types, thought to be representative of least impacted streams, to establish an expected or reference range of temperatures.
- Fish population data should be collected on reference streams in order to evaluate

appropriateness of designated uses.

- The need for a regionalized temperature standard should be reviewed.
- This proposal should be evaluated over time, and a new standard criterion should be developed from this review that will eventually be proposed to replace the single-value temperature criterion currently specified in the New Mexico Surface Water Quality Standards.

References

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* The date on the publication that DM Tarzwell edited is 1960, Brett’s title conflicts.

Appendix A

New Mexico Environment Department/Surface Water Quality Bureau Protocol for Deployment and Evaluation of Long-term Thermographs

Monitoring Timing, Frequency and Duration

Monitoring for temperature should generally be conducted from May through September to be consistent with periods when incident solar radiation angles are high and ambient air temperatures are most likely to be at maximums. Knowledge of regional patterns is important if monitoring duration must be limited to periods shorter than the interval described above. Monitoring should always include the period of critical maximum expected temperatures.

When monitoring data are to be used to make assessments of designated use support maximums, duration and rate of temperature increase must be collected. For these purposes, the recording thermograph is the most useful tool. For a recording thermograph, monitoring frequency should be adequate to provide a realistic estimate of the maximum temperature and duration of criteria exceedences. If data are collected at too large an interval, maximum temperatures and durations are likely to be missed. **The SWQB maximum interval for monitoring for standards attainment, with a recording thermograph, is one hour.** Obviously, shorter intervals provide a more precise estimate of the duration of daily maximums. For this reason, shorter intervals may be used with no impact to data quality. However, this is a trade-off against data storage limitations. One approach to this problem is use of a pilot period of monitoring, with at least thirty-minute monitoring intervals, to determine how rapidly stream temperature may change. The need for a shorter monitoring interval is more important on smaller, coldwater streams than larger streams.

Monitoring Equipment

Thermographs must be waterproof and have a temperature range that is appropriate for the applicable standard. Devices should have a minimum temperature range of –5°C to 40°C, with minimum resolution and accuracy of ±0.5°C within this range. They should be capable of recording at a wide range of intervals with a minimum of no more than fifteen minutes and a maximum greater than two hours. The thermograph must be capable of direct download to a PC, creating a file that is exportable to currently available spreadsheet software.

Where to Monitor

Thermographs should be placed in stream locations that are representative of ambient stream conditions. For this reason, thermographs should not be placed in shallow riffles or in deep pools. Generally, the thermograph should be deployed in a transition between a riffle/run and a pool. If possible, the thermograph should be placed at the toe of a pool as it becomes more shallow, prior to entering a run or riffle. The thermograph should be placed such that under expected flow conditions it will be continuously submerged. If possible, the thermograph should be located under shading to eliminate direct solar gain.

Field Equipment

Actual situations encountered during thermograph deployment will vary. Consequently, this protocol offers only very general recommendations for thermograph deployment. Consideration should be given to the list of conditions in the section entitled "Where to Monitor."

Typical equipment that should be available includes:

- plastic zip ties
- surveyors marking tape
- iron rebar stakes (minimum 18 inches)
- sledge hammer
- wire cutters and knife
- portable computer and interface, as needed by your equipment
- auditing thermometer
- timepiece
- field book or data sheets
- camera and film

Precautions against vandalism, theft, and accidental disturbance should be considered when deploying equipment. In areas frequented by the public, it is advisable to secure or camouflage equipment. Visible tethers are not generally advisable, since they attract attention. If such tethers are deemed necessary, they should be buried or hidden.

Quality Assurance and Quality Control

The following procedures must be followed to ensure that temperature data are of acceptable quality. These procedures document instrument accuracy, test for proper functioning during the deployment period, and set criteria for data acceptance.

Accuracy Testing and Recording

A National Institute of Standards and Technology (NIST) traceable thermometer, with a resolution and accuracy of 0.1°C or better, should be used to test thermograph accuracy prior to deployment. The NIST thermometer should be calibrated annually, with a minimum of two temperatures. If a NIST thermometer is not available, a good quality thermometer calibrated against an NIST thermometer may be used. This thermometer should also be calibrated annually, with a minimum of two temperatures.

Accuracy of the thermograph must be tested pre- and post-deployment, at a minimum of two calibration temperatures between 0°C and 25°C. Testing is done using a stable thermal mass, such as an ice water bath or other controlled water bath. The stable temperature of the insulated water mass allows direct comparison of the unit's readout with that of the certified or calibrated thermometer. Accuracy should be within ±0.5°C. A logbook must be kept that documents each unit's calibration date, test result, and the reference thermometer used.

Field Auditing of Instrument Performance

In addition to laboratory calibrations, temperature monitoring equipment may be audited during deployment. A field audit is a comparison between the temperature of the field probe and a properly calibrated mercury thermometer. The purpose of this procedure is to ensure thermograph accuracy. Two field audits are recommended: one at the time of deployment, after the instrument has reached thermal equilibrium, and one at the time of recovery. Other periodic audits are recommended to assure proper functioning and to minimize data loss.

Thermometers for audits should have an accuracy and resolution of ±0.5 °C. The audit is performed by placing a thermometer as close as possible to the thermograph's sensor. The audit value is recorded when the temperature stabilizes. If the thermograph allows for the auditor to view real-time temperature data without interfering with sampling, it is possible to do a "real-time" audit. If the thermograph does not allow this feature, the audit must necessarily be conducted by "post-processing" of recorded data. In this case, recorded data are off-loaded and compared later to recorded audit values. For this type of audit, recording times of the device and recorded auditing times should be as synchronous as possible. The thermograph will have a date and time based on the set-up computer's internal clock. The timepiece used for the audit should be synchronized with the computer's clock to reduce time-induced error.

Data Review and Reduction

Data will be retained in raw form without post-processing. Only data that meet quality control requirements may be used for comparison to numeric temperature criteria. Data are considered valid if they pass pre- and post- calibration and field audits.

All data will be reviewed for any obvious anomalies. Since these devices are left for long periods of time without supervision, they may be subject to external forces or conditions that may render some of the data questionable. Examples of such conditions may include being picked up by persons other than sampling personnel or being exposed to ambient air temperature as water levels drop below the sensor. These problems can be minimized through proper deployment of the devices and a complete data review to document anomalous or apparently unnatural data.